Stressor-Response Relationships – Nutrients: Dissolved Oxygen and Benthic Response (WQ MYP)

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Agency Problem

EPA's Office of Water and states require approaches and methods to develop and apply criteria that will support designated uses for aquatic systems. Effects-based solution to this problem requires determination of quantitative and causal relationships between nutrient loading and ecological responses for coastal aquatic resources. This poster specifically addresses linkage between nitrogen loading and degradation of benthic habitat quality, including reduced concentrations of dissolved oxygen (DO). These relationships can provide the Office of Water with the scientific basis required to develop numeric nutrient criteria protective of aquatic life, and thereby provide scientifically valid approaches for protecting the ecological integrity of aquatic ecosystems from excess nutrients, in support of EPA's goal to provide clean and safe water.

Research Goals

To quantify relationships between nutrient loading and benthic response for development of numeric nutrient criteria protective of aquatic life.

Anticipated effects of increased loading of nitrogen to estuarine systems include increased frequency and/or duration of hypoxia and a general degradation of the quality of benthic habitat. Two approaches have been used to assess the degree of these effects:

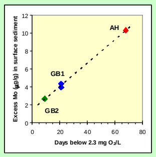
- use of sediment profile imagery (SPI) to measure both physical and biological indicators of benthic condition at the sediment-water interface
- measurement of the element molybdenum (Mo) in sediments as a geochemical marker of the duration of hypoxic conditions

Hypoxic conditions may also affect activity of benthic organisms, which in turn may affect sediment biogeochemical properties, so we have investigated the effects of hypoxia on the burrowing behavior of three common estuarine species, and consequent effects of said burrowing on those properties.

Use of Molybdenum as a Marker oHypoxic Conditions

Methods & Approach

Preliminary field studies (right) have shown that molybdenum (Mo) accumulates in sediments under hypoxic water conditions and that the accumulation can be related to the duration and intensity of those conditions



In order to use molybdenum concentrations in sediments to determine the duration and intensity of prior hypoxic periods, we set out to:

- determine the accumulation rate of Mo in sediments as a function of DO concentration under controlled exposures (laboratory)
- verify rates derived from laboratory experiments in field sediments having concurrent and historical measurements of DO

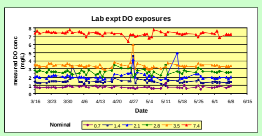
Once verified, accumulation rates of molybdenum in sediments may be used to determine the temporal extent of hypoxia in New England estuaries

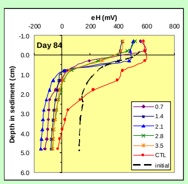
- Mo in surface sediments reflects occurrence of hypoxia integrated over multi-year time frame, should reflect longer term trends in N loading and benthic response
- Mo concentrations less variable temporally than SPI analyses, less stringent requirements on time of sampling.

Results

Greenwich Bay sediment (3.4% TOC) exposed to seawater with controlled concentrations of dissolved oxygen

- 5 levels in range of 0.7 – 3.5 mg/L and control (saturated)
- Sediments sampled biweekly for 12 weeks





Redox profiles reveal alteration in sediment conditions

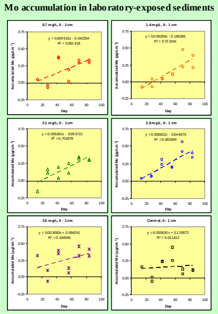
- After 84 days, all sediments except controls more reduced than initial conditions, with redox potential discontinuity (RPD) 0.5 – 1 cm below sediment surface
- In control exposure, surface sediments oxidized relative to initial condition

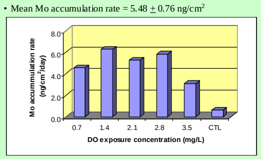
Hypothesized that Mo should accumulate at a rate independent of DO concentration below critical value, estimated from field observations as ~3 mg/L

Slopes of Mo vs. time in exposures provide authigenic accumulation rates

- Experimentally determined rates essentially constant for exposures < 3 mg/L, decrease at higher concentrations
- Mean Mo accumulation rate = 5.48 $\pm$ 0.76 ng/cm^2

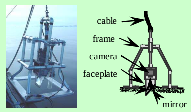
Mo accumulation in laboratory-exposed sediments





Ratio of Mo accumulation rate determined in field sediment to laboratory rate should provide frequency of hypoxic conditions

Sediment Profile Imagery (SPI) and Nutrient Pollution



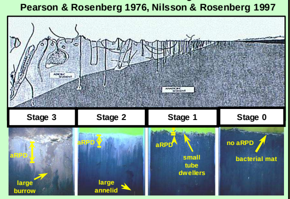
Methods & Approach

Sediment profile cameras image the sediment in cross-section and are rapid to use in the field, allowing good spatial coverage.

We analyzed images using the Nilsson and Rosenberg (1997) Benthic Habitat Quality (BHQ) index (range: 0-15), calculated from evidence of benthic infauna and depth of the apparent Redox Potential Discontinuity (aRPD).

- BHQ Stage = "successional" stage derived from BHQ after Nilsson and Rosenberg (1997), corresponds to ranges of BHQ
- modified by adding Stage -1 for BHQ = 0 to provide better resolution, as our data clustered at the low end of the range

Benthic Successional Stages after Pearson & Rosenberg 1976, Nilsson & Rosenberg 1997

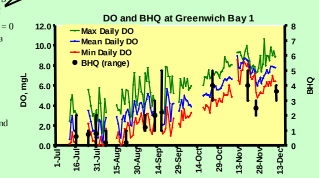


Stage	0	1	2	3
BHQ	< 2	2-4	5-10	> 10

Results

1) We tested correlations between BHQ and measured DO in a field experiment. Data from one of three stations are shown.

DO and BHQ at Greenwich Bay 1

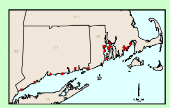


BHQ identified environments that had experienced relatively high or low DO over the preceding four weeks (Cicchetti et al. 2006)

2) We are producing a technical guidance document for consistent analysis of sediment profile images, based on expert consensus from a workshop we hosted.

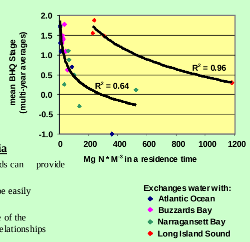
3) We examined relationships between estimated N loading (estimated using a watershed model and adjusted for estuarine volume and residence time – see accompanying poster) and benthic condition for 29 small estuarine systems on Southern New England's coastline.

- Narragansett Bay: 8 systems - 2000, 2001, 2003
- Buzzards Bay/Islands: 13 systems - 2001
- Connecticut/Block Island: 8 systems - 2003



We found significant relationships between BHQ and estimates of nitrogen load for classes of systems. But:

- A large part of variability in these relationships was not accounted for by the factors we considered
- Further explorations of data are needed to examine other factors to account for variability



Development of Nutrient Criteria

Comparative empirical approaches based on SPI methods can provide the type of data needed to develop nutrient criteria.

- SPI results relate to DO and nutrient load, and can be easily communicated as ecological effects
- Comparative empirical approaches can bypass some of the complexity of natural systems to produce working relationships
- Classification and normalization are required, e.g, for system morphology, residence time of water in estuary, etc.
- Predictions are limited to classes of systems that were sampled for model construction.

Influence of Hypoxia on Bioturbation

Methods & Approach

AED's state-of-the-art dissolved oxygen facility used to investigate burrowing behavior

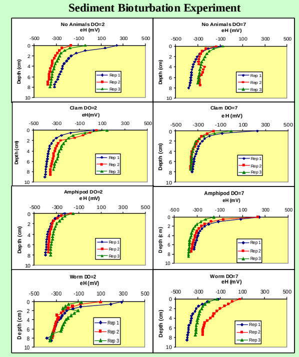
- three common estuarine species (the hard clam *Mercenaria mercenaria*, clam worm *Nereis virens*, and amphipod *Leptocheirus plumulosus*)
- normoxic (7 ppm) and mildly hypoxic (2 ppm) conditions.
- examined burrow construction by CT scanning sediment cores at a local hospital
- examined redox profiles using a Pt-tipped combination microelectrode
- experiment conducted for four months, with periodic measurements of redox profiles

Results

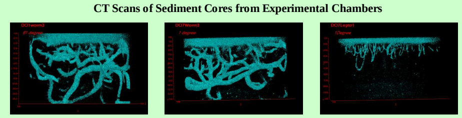
eH profiles

- Profiles of redox potential were affected by dissolved oxygen concentration, but not by the presence of animals
- No interaction effect of dissolved oxygen concentration and species on redox potential profile
- Results suggest that dissolved oxygen concentrations did not influence the animals' impact on sediment redox chemistry

Sediment Bioturbation Experiment

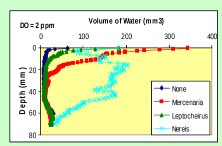


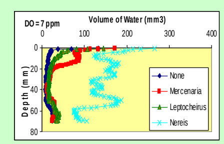
CT Scans of Sediment Cores from Experimental Chambers



Nereis virens, mildly hypoxic — *Nereis virens,* normoxic — *Leptocheirus plumulosus,* normoxic

CT scan images show burrows made by the polychaete *Nereis virens* and the amphipod *Leptocheirus plumulosus*. By viewing only voxels (3-D pixels) having the same density as water, we are able to view burrows made by animals.





Animals did affect the amount of water in the sediment (i.e. burrows)

- No interaction of dissolved oxygen concentration and species, suggesting hypoxic conditions did not affect animals' burrowing behavior
- Measurements of burrow depth and density were inconclusive, showing no statistical difference but seeming to indicate that if animal density was increased, results may be discernible

Impact and Outcomes

Ultimate goal: development of stressor-response models to inform establishment of effects-based numerical criteria for nutrients

- Current research is developing tools and approaches that will enable more rapid assessment of degraded benthic conditions over greater spatial scales and better integrate the effects of benthic stress over time and space
  - assessments may integrate stressors/effects over short (3-4 week) (SPI) or long (2-10 year) term (Mo).
  - could be incorporated into regional sediment monitoring programs
  - DO/benthos interactions serve to refine our understanding of what constitute critical levels of DO and nutrient loading to water bodies and gain a more complete understanding of the role nutrient enrichment plays in benthic ecosystems, including effects more subtle than survival alone
- Stressor-response models constructed through use of these tools will enable Agency to provide more precise and reliable quantitative estimates of effects of added nutrients in estuarine systems
  - should provide the basis for development of numerical criteria for nutrients in coastal embayments, ability to predict improvement in benthic condition in response to nutrients management options
  - implementation of criteria in turn should result in a healthier, more diverse and productive benthos, in addition to reduced impacts in other portions of coastal systems (see related posters)

Future Directions

Sediment profile imagery:

- Identify issues with benthic response model, revise and validate model, including:
  - residence time submodel to include restrictions
  - N loading submodel to include seawater N inputs, other N or carbon inputs, freshwater flow
  - stratification
  - sampling strategy
- Determine how to link benthic response to other project/model components and to management/client needs

Use of Mo as indicator of hypoxic conditions:

- Verify laboratory-derived accumulation rates in field sites
- comprehensive sampling of surface sediments from New England estuarine systems
- Assessment of frequency/duration of hypoxic conditions
- Examine correlation between estimated nitrogen loading and frequency/duration of hypoxic conditions (as with SPI analyses)

Repeat benthic activity experiments using lower levels of dissolved oxygen

- Experiment involved relatively mild level of hypoxia (2 mg/L), possible more severe hypoxia will have greater effects on animal behavior and consequent effects on sediment redox potential
- test other common burrowing species using a similar experimental design

References

Cicchetti, G., J.S. Latimer, S.A. Rego, W.G. Nelson, B.J. Bergen and L.L. Coiro. 2006. Relationships between near-bottom dissolved oxygen and sediment profile camera measures. *Journal of Marine Systems* 62: 124-141.

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